ARMY RESEARCH LABORATORY

Energy Cost of Walking in Four Types of Snowshoes

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Abstract

Energy cost was examined while four Marines walked at 4 km/hr on an open field with each of four snowshoes. Snowshoes were the Pride Assault, Montana, British Assault, and the U.S. Army Standard. The grade of the field was about 2.4% and the Marine walked once downhill and once uphill with each snowshoe. Expired respiratory gases were collected continuously during each walk. On the downhill portion of the course, average ± standard deviation (SD) VO_2 values were 1.25±0.13, 1.46±0.11, 1.31±0.13, and 1.22±0.20 l/min for the Pride, Montana, British, and Standard snowshoes, respectively (p=0.01); the Pride and Standard snowshoes had significantly lower energy cost than the Montana (p=0.05). On the uphill portion of the course, average ± SD VO_2 values were 1.58±0.12, 1.7±80.14, 1.62±0.21, and 1.5±10.06 l/min for Pride, Montana, British, and Standard snowshoes, respectively (p=0.06). Data suggested that several characteristics may be favorable from an energy cost perspective: 1) a foot hinge and binding system that allows the snowshoe to be dragged across the snow, 2) an upturned front that pushes snow away and allows a more horizontal displacement of the snowshoe during locomotion, and 3) a lower mass-to-surface-area ratio. Further research will be necessary to determine the relative importance of these design characteristics, given the small number of subjects.

ACKNOWLEDGMENTS

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EXECUTIVE SUMMARY

Energy cost was examined while Marines walked in each of four snowshoes: the Pride Assault, Montana, British Assault, and the U.S. Army Standard. Four male Marine volunteers wearing only battle dress uniforms (BDU) and Gortex parkas walked with each snowshoe at 4 km/hr on an open field. Walking velocity was established by a pace setter who called the speed every 30 m; the Marine adjusted his pace based on this feedback. Grade of the field was about 2.4% and the Marine walked once downhill and once uphill with each snowshoe. Each walking segment was 336 meters long and took about 5 minutes to complete. While the Marines walked, heart rates and expired respiratory gases were collected continuously. Heart rate was measured with a Polar Vantage XL® heart rate device, and expired gases analyzed for oxygen content (VO_2) using an Oxylog2®. Overall snowshoe flotation was measured from snowshoe prints by averaging the depth of depression on the medial, lateral, and posterior sides. Snow conditions were 8 cm of new powder on a 60-cm base. On the downhill portion of the course average ± standard deviation (SD) VO_2 values were 1.25±0.13, 1.46±0.11, 1.31±0.13, and 1.22±0.20 l/min for the Pride, Montana, British, and Standard snowshoes, respectively (p=0.01). Post hoc analysis indicated that the Pride and Standard snowshoes had significantly lower energy cost than the Montana (p=0.05). On the uphill portion of the course average ±SD VO_2 values were 1.58±0.12, 1.78±0.14, 1.62±0.21 and 1.51±0.06 l/min for Pride, Montana, British, and Standard snowshoes, respectively (p=0.06). There were no significant differences among the snowshoes on overall flotation; average depth of depression was about 5 cm. The Pride and Standard snowshoes differed from the Montana in several characteristics, suggesting that these characteristics may be favorable from an energy cost perspective. These characteristics were 1) a foot hinge and binding system that allows the snowshoe to be dragged across the snow, 2) an upturned front that pushes snow away and allows a more horizontal displacement of the snowshoe during locomotion, and 3) a lower mass-to-surface-area ratio (lighter snowshoe combined with a greater area on the snow). Further research will be necessary to determine the relative importance of these design characteristics, given the small number of subjects in this investigation.

THE ENERGY COST OF WALKING IN FOUR TYPES OF SNOWSHOES

Weather is not only to a great extent the controller of the conditions of ground but also of movement.

-- Major General J.F.C. Fuller, The Foundations of the Science of War, 1926

...the Russian land which he dreams of enslaving will be strewn with his bones. We will pursue tirelessly. Let winter, blizzards, and the cold come. We know them.

-- Field Marshall Prince Mikhail Kutuzov, 1812, speaking with his troops during Napoleon's invasion of Russia (Sbornik dokumentov, 1955).

INTRODUCTION

Cold climates with large amounts of ground snow cover pose significant challenges for military operations. One of these challenges is the ability of foot soldiers to traverse over the snow. A dramatic example of how military success was influenced by effective mobility across snow occurred in the winter of 1939-1940 when the Soviet Army invaded Finland. At the Battle of Suomussalmi, the Finnish Ninth Infantry Division defeated the combined strength of the Soviet 163th Infantry Division and 44th Motorized Rifle Division despite the Soviet's two- or three-to-one numerical advantage. The Finnish Army had trained in the snow and knew how to quickly and efficiently move across it (Thompson, 1995).

Two major methods of movement in deep snow are skis and snowshoes. Snowshoes are by far the easier method for American soldiers to learn; it has been estimated that skillful movement over open terrain can be acquired in about 1 hour of training (Thompson, 1995). Despite the perceived usefulness of snowshoes for mobility over snow, there are few investigations examining the effectiveness of this mode of transportation for military operations (Hickey, Knapik, Ortega, & Nagel, 1996; Hickey, Hanlon, & Oblak, 1994).

One characteristic of the snowshoe that can become very important in a military environment is the energy cost. Compared to temperate environments, cold climates require soldiers to carry a greater quantity of clothing and equipment in order to combat weather-related problems. This additional load taxes the soldier's energy reserves. A snowshoe that has a low energy cost would be favored over one with a higher energy cost. The lower energy cost item would help the soldier conserve strength for other tasks.

The major purpose of this investigation was to determine the energy cost of four snowshoes. A secondary purpose was to determine some of the factors that may account for the differences in energy cost among the snowshoes.

BACKGROUND

It is often assumed that human energy cost is increased in cold weather. Cold exposure can increase energy cost if the individual is inadequately clothed and shivering occurs. Shivering is the forcible contraction of one muscle group against its antagonist and can increase resting energy expenditure as much as 5 times (Adolph & Molnar, 1946). On the other hand, there is probably little or no measurable increase in energy expenditure in an adequately clothed individual because a microclimate is created around the body through the trapping of warm air in clothing which maintains body temperature. Some increases in energy expenditure might be expected to be attributable to a) warming and humidifying cold air breathed into the body, b) warming of cold air brought into the clothing, and c) the additional weight of equipment and clothing that must be carried in field environments (Askew, 1989; Buskirk & Mendez, 1967). However, during controlled laboratory conditions, energy cost is the same in a temperate (26° C to 20° C) and a cold (5° C to -20° C) environment, provided the exercise intensity is sufficient to cause heat transfer from the body to the environment (Patton & Vogel, 1984; Stromme, Andersen, & Elsner, 1963). Further, with physical activity of sufficient intensity, core and extremity temperature can be easily maintained (Virokannas, 1996). Patton and Vogel (1984) had subjects perform cycle ergometer exercise at 175 watts (approximately 75% VO_2 max) to exhaustion and found no difference in energy cost whether subjects exercised at -20° C or +20° C.

Much work has been done on the energy cost of human locomotion. Energy cost increases in a systematic manner with increases in body mass, load mass, velocity, and/or grade (Bobbert, 1960; Borghols, 1978; Goldman & Iampietro, 1962; Soule, Pandolf, & Goldman, 1978). Type of terrain also influences energy cost (Haisman & Goldman, 1974; Pandolf, Haisman, & Goldman, 1976; Soule & Goldman, 1972). Pandolf, Givoni, and Goldman (1977) used these relationships to develop an equation for predicting energy cost of locomotion with loads:

$$M_W = 1.5 \cdot W + 2.0 \cdot (W+L) \cdot (L/W)^2 + T \cdot (W+L) \cdot (1.5 \cdot V^2 + 0.35 \cdot V \cdot G)$$

in which M_W = Metabolic cost of walking (watts)

W = Body mass (kg)

L = Load mass (kg)

T = Terrain factor (coefficients shown below)

1.0 = Black top road

1.1 = Dirt road

1.2 = Light brush

1.5 = Heavy brush

1.8 = Swampy bog

2.1 = Loose sand

V = Velocity or walk rate (m/sec)

G = Slope or grade (percent)

Critical to this equation is the terrain factor. The terrain factor is an empirically derived number based on studies examining energy cost in various terrains. Energy expenditure during walking in the snow appears to be largely dependent on the depth to which the individual sinks into the snow (Heinonen, Karvonen, & Ruosteenoja, 1959; Pandolf et al., 1976; Ramaswamy, Dua, Viswanathan, Madhaviah, & Srivastava, 1966). Pandolf et al. (1976) demonstrated a rise in energy cost as the depth of depression increased. The terrain factor for walking in snow could be estimated from the equation:

$$T = 1.30+0.082D$$

in which T = Terrain Factor and D = depth of the depression (in cm).

The Pandolf equation was developed for predicting the energy cost of locomotion with boots. Placing snowshoes on the boot complicates the metabolic picture. In addition to the factors mentioned (body mass, load mass, velocity, and grade), certain characteristics of the snowshoe might be expected to influence energy cost. A snowshoe with a larger surface area may result in greater flotation (i.e., how well the snowshoe keeps a person from sinking into the snow), thus reducing the depth of depression, and consequently reducing energy cost (Pandolf et al., 1976; Ramaswamy et al., 1966). The total mass of the snowshoe may also be important. Any increase in load mass will increase energy cost, but loads carried on the feet are especially expensive since they result in an energy cost five to seven times higher than an equivalent load carried on the upper body (Legg & Mahanty, 1986; Soule & Goldman, 1969). For each 1 kg added to the foot, the increase in energy expenditure is 7% to 10% (Catlin & Dressendorfer, 1979; Jones, Toner, Daniels, & Knapik, 1984; Legg & Mahanty, 1986; Soule & Goldman, 1969). Thus, factors relating to flotation, surface area, and snowshoe mass must be considered in the energy cost of walking in snowshoes.

Few studies have examined energy cost during locomotion in snowshoes and all these studies have neglected critical variables. Buskirk et al. (1956) made nine determinations on eight men walking at 3.7 km/hr. They found an average energy cost of 6.21.1 kcal/min or an oxygen uptake of 1.28 l/min (17.5 ml/kg*min). Neither the snowshoe characteristics nor depth of snow is reported. Rodgers, Buck, and Klopping (1965) report individuals walking at 3.7 km/hr with snowshoe prints about 9 cm deep. They estimated that oxygen uptake was 2.45 l/min (35ml/kg*min) for one man. They do not provide the type of snowshoe used or its characteristics. Allen and O'Hara (1973) studied nine infantrymen carrying equipment estimated at 23 to 27 kg, traveling at 2 to 3.6 km/hr. They found an average energy expenditure of 4.83±1.51 kcal/min or 0.980.30 l/min. Walking pace was highly variable and the depth of depression and snowshoe type were not reported. Worsley (1974) reported a number of soldiers walking in snowshoes with packs at various speeds where the depth of depression did not exceed 5 cm. During the conditions of their study, oxygen uptake (ml/kg*min) could be predicted from the equation -1.3+0.33*speed (m/min) over a range of speeds from about 40 to 100 m/min (2.4 to 6 km/hr). However, pack mass was not provided, nor was the grade of the terrain the soldiers traversed.

OBJECTIVE

The major objective of this investigation was to measure the energy cost of locomotion in four types of snowshoes. The secondary objective was to examine some factors that may influence energy cost of snowshoeing.

METHODS

Subjects

Subjects were four Marines who volunteered for this investigation after a full briefing about the purposes and risks. They signed an informed consent statement in compliance with Army Regulation 70-25. The study was approved by the institutional Human Use Review Committee.

Marines had previously trained one day with each snowshoe before the energy cost studies as part of another investigation (Hickey et al., 1996). Training consisted of identical morning and afternoon sessions. These involved a 30- to 45-minute walk in the snowshoe, a run up and down a steep hill and a sprint on a 75-m assault course. On the walk, a variety of terrain was encountered, including level areas, rolling hills, and steep slopes (uphill and downhill). The

75-m sprint involved completing the distance as fast as possible while assuming a prone rifle-firing position twice at specific intervals on the course. Marines wore the snowshoes around the camp during the time they were not being tested.

Anthropometry

Marines' total body mass was obtained from a digital scale (Seca) and stature from an anthropometer (GPM). Age was determined from the date of their last birthday. Circumferences were obtained from the neck and abdomen using a fiberglass tape measure (Gulick). Body fat was estimated from anthropometric measurements (Vogel, Kirkpatrick, Fitzgerald, Hodgdon, & Harman, 1984) and fat-free mass by subtracting body fat mass from total body mass.

Trochanterion height (total leg length) was measured with an anthropometer from the floor to the femoral trochanter with the subject in the standing position, heels together, and weight evenly distributed on each foot (Gordon et al., 1989). Calf length was measured with an anthropometer between the knee joint line and tip of the medial malleolus (tibia distance) with the subject in a seated position and knees crossed (Lohman, Roche, & Martorell, 1988). Thigh length was measured with a fiberglass tape from the midpoint of the inguinal ligament to the proximal edge of the patella with the subject standing and the measured leg on a chair such that the knee was at a 90^{o} angle (Lohman et al., 1988). All these measurements were made on the right leg.

Apparatus

Snowshoes

Four snowshoes (the Pride Assault, the Montana, the British Assault and the U.S. Army Standard snowshoe [trail magnesium]) were tested. The Pride Assault snowshoe (see Figures 1 and 2) consisted of an aluminum frame to which a solid plastic membrane was attached with 20 plastic loops. The front of the frame was turned upward. The boot binding system (see Figure 1) was attached to the aluminum frame by a plastic-covered piece of steel that allowed the binding to pivot as the subject walked. The binding consisted of single piece of aluminum with upturned sides to prevent lateral and medial boot slippage. When the boot entered the binding, a clip at the rear forced the boot against a front cable and firmly locked it into the binding. A single adjustable strap on the rear clip was secured around the ankle to minimize the possibility of the clip coming off. On the underside of the Pride were two crampons (see

Figure 2), one of which pivoted with the binding as the subject walked. The other crampon was fixed under the snowshoe at about the level of the heel.

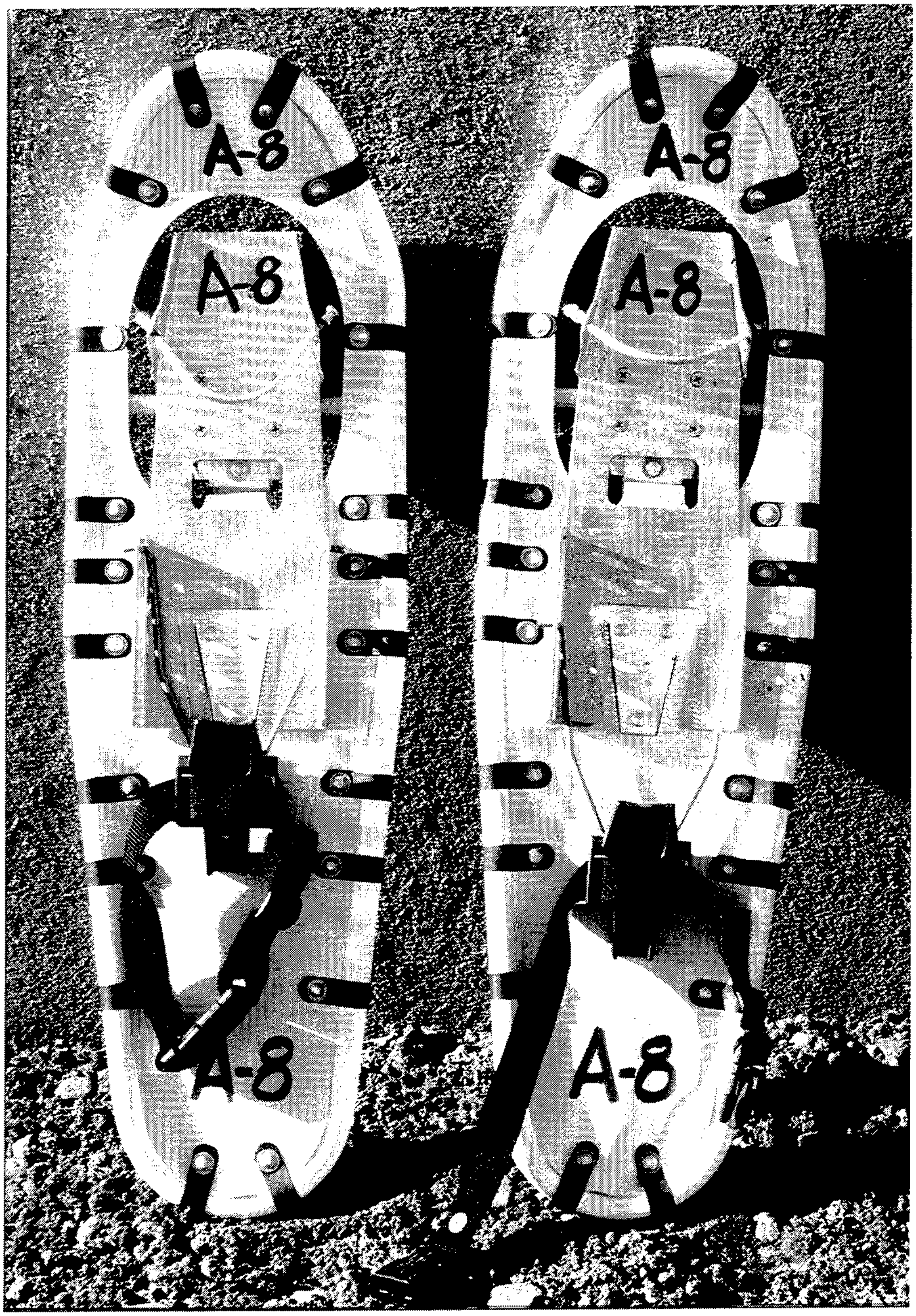

Figure 1. Top view of pride assault snowshoe.

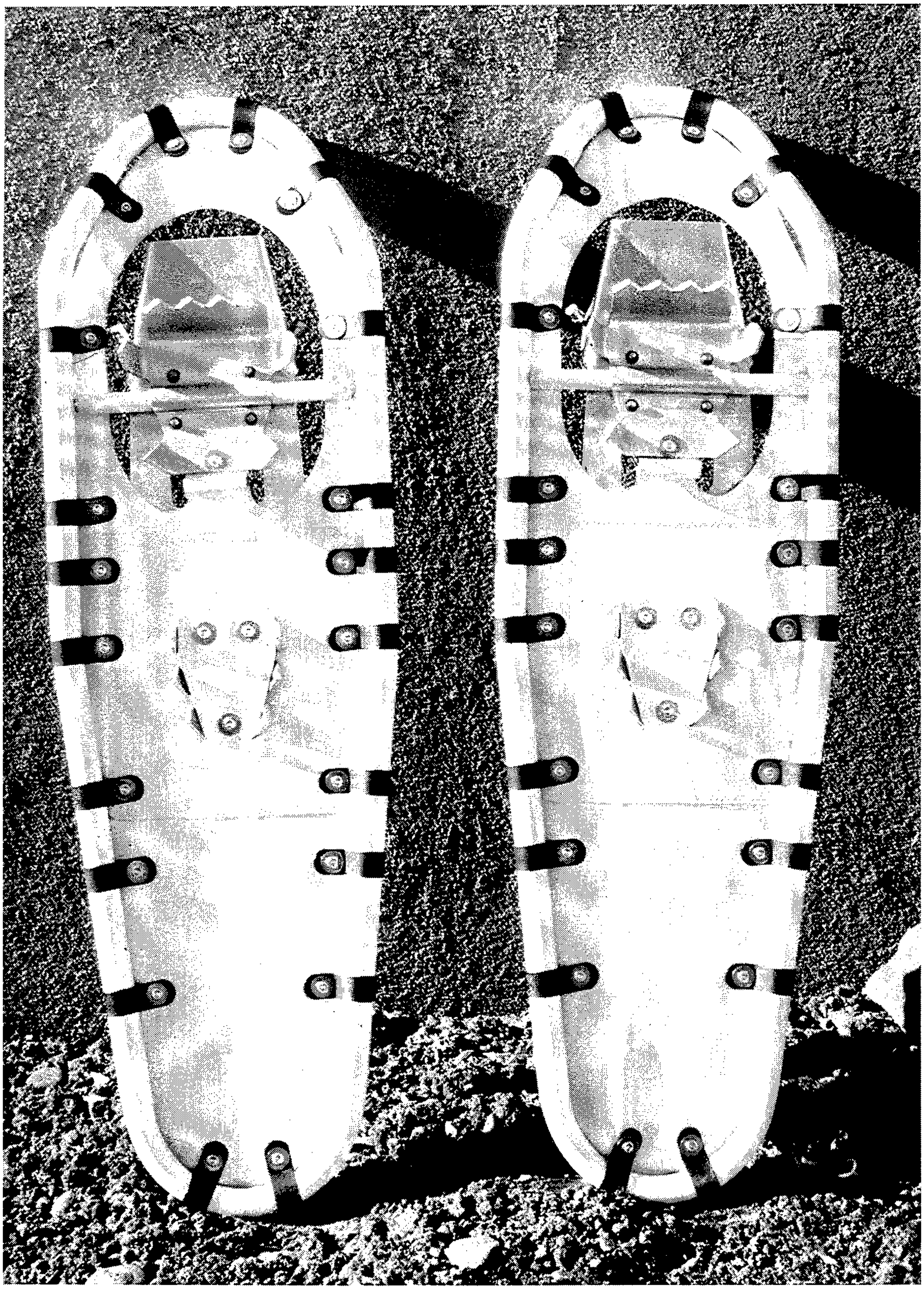

Figure 2. Bottom view of pride assault snowshoe.

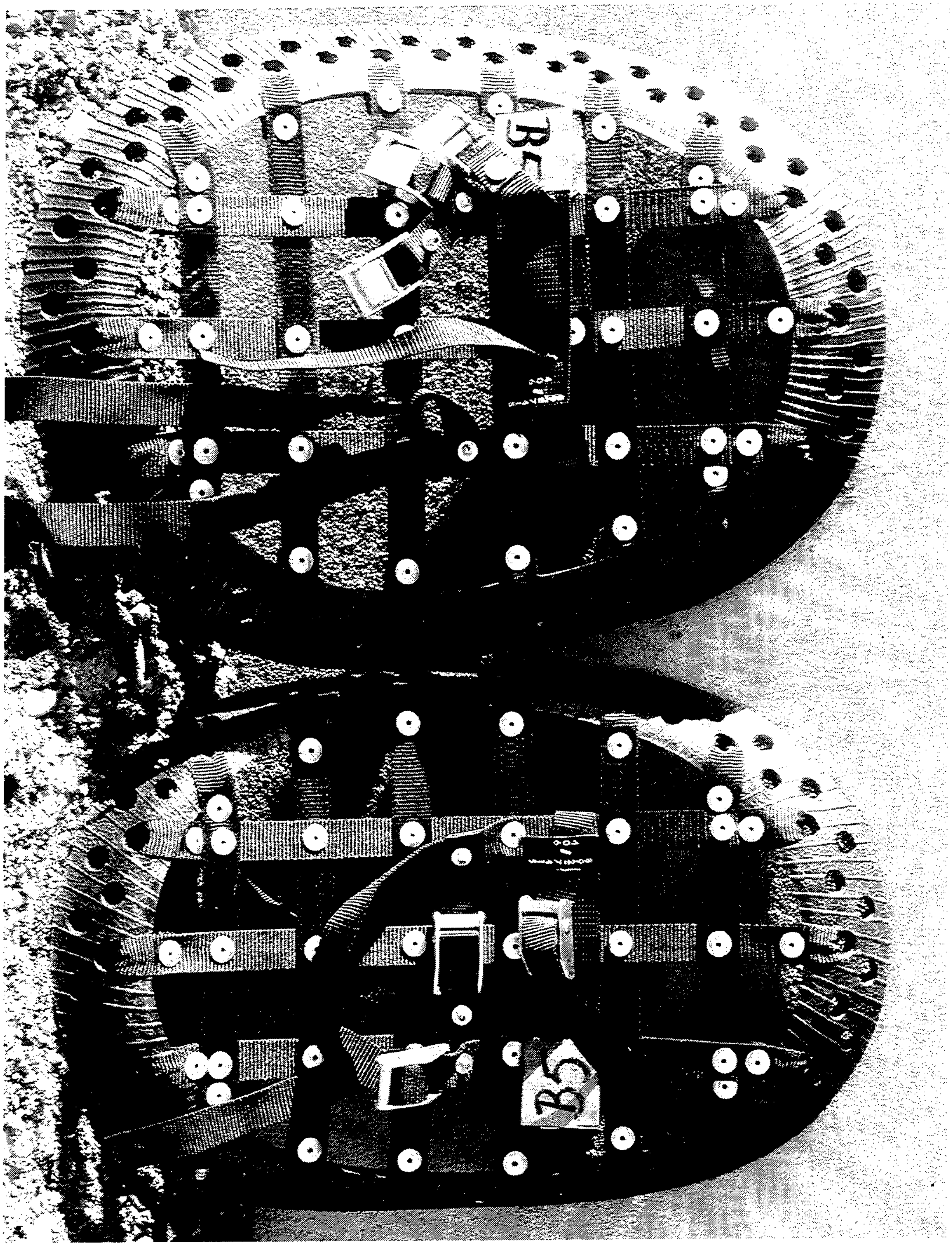

Figure 3. Top view of Montana snowshoe.

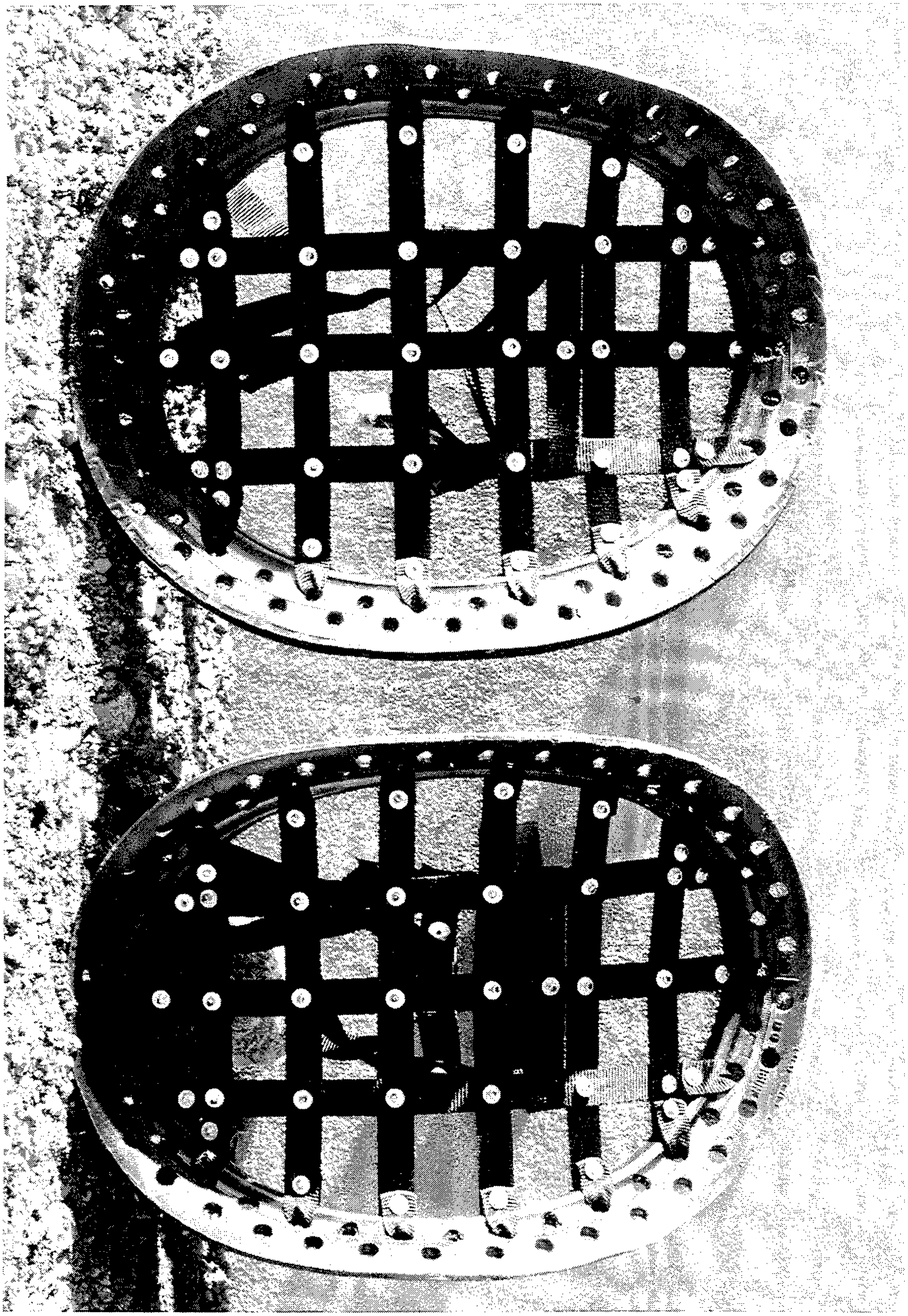

Figure 4. Bottom view of Montana snowshoe.

The Montana snowshoe (see Figures 3 and 4) was a rubber tire into which holes had been drilled. Fabric webbing was looped through some of these holes and the webbing formed a crisscrossed network inside the tire. The nine pieces of webbing were riveted at crossing points. The boot binding system consisted of three straps riveted to the webbing; all three straps were adjustable using buckles. Two straps ran over the tops of the boot and one across the heel.

The British Assault snowshoe (see Figures 5 and 6) consisted of a plastic (polyvinyl chloride [PVC]) frame with nine crisscrossed straps riveted at crossing points. The boot binding system consisted of 1) a plastic strap that ran over the top of the boot, 2) a fabric strap for the front of the ankle, and 3) a fabric strap than ran from the front of the boot to around back of the heel. All three straps were adjustable with buckles. On the underside of the snowshoe (see Figure 6) were two crampons arranged at about a 45° angle to the long axis of the snowshoe. The crampons were attached to the aluminum frame and to a single thin strip of metal near the front of the snowshoe.

The U.S. Army Standard snowshoe (see Figures 7 and 8) had a metal frame with two metal supports approximately perpendicular to the frame. The metal frame tapered to a long tail in the rear of the snowshoe and the front of the snowshoe was turned upward. Plastic-covered wires crisscrossed the frame. The boot binding system consisted of three fabric straps that went around the top of boot, heel, and ankle. The straps were adjustable with buckles.

Measurement of Snowshoe Characteristics

The mass of each snowshoe was measured using a digital scale. Length and width were measured with a ruler at the longest portions of each snowshoe.

Surface areas were determined by manual planimetry. Two outlines of each snowshoe were traced on a large sheet of paper. Tracings were performed on the flat and anterior curved portions of the snowshoe. The flat portion was that part of the snowshoe which was in contact with the surface when the snowshoe sat on a level platform. The curved portion was the front upturned part of the snowshoe (only present on the Pride and Standard models). Curvature outlines were obtained by rolling the snowshoe forward on the paper and then tracing this portion. To determine the limit of the curvature, 1) the snowshoe was placed back down on the tracing a second time, 2) a thin ruler was slipped under the front part of the shoe until the snowshoe stopped the ruler, 3) the snowshoe was removed, and 4) a straight line was drawn

across the tracing where the ruler rested. The curved area was the area encompassed by the line and front part of the shoe.

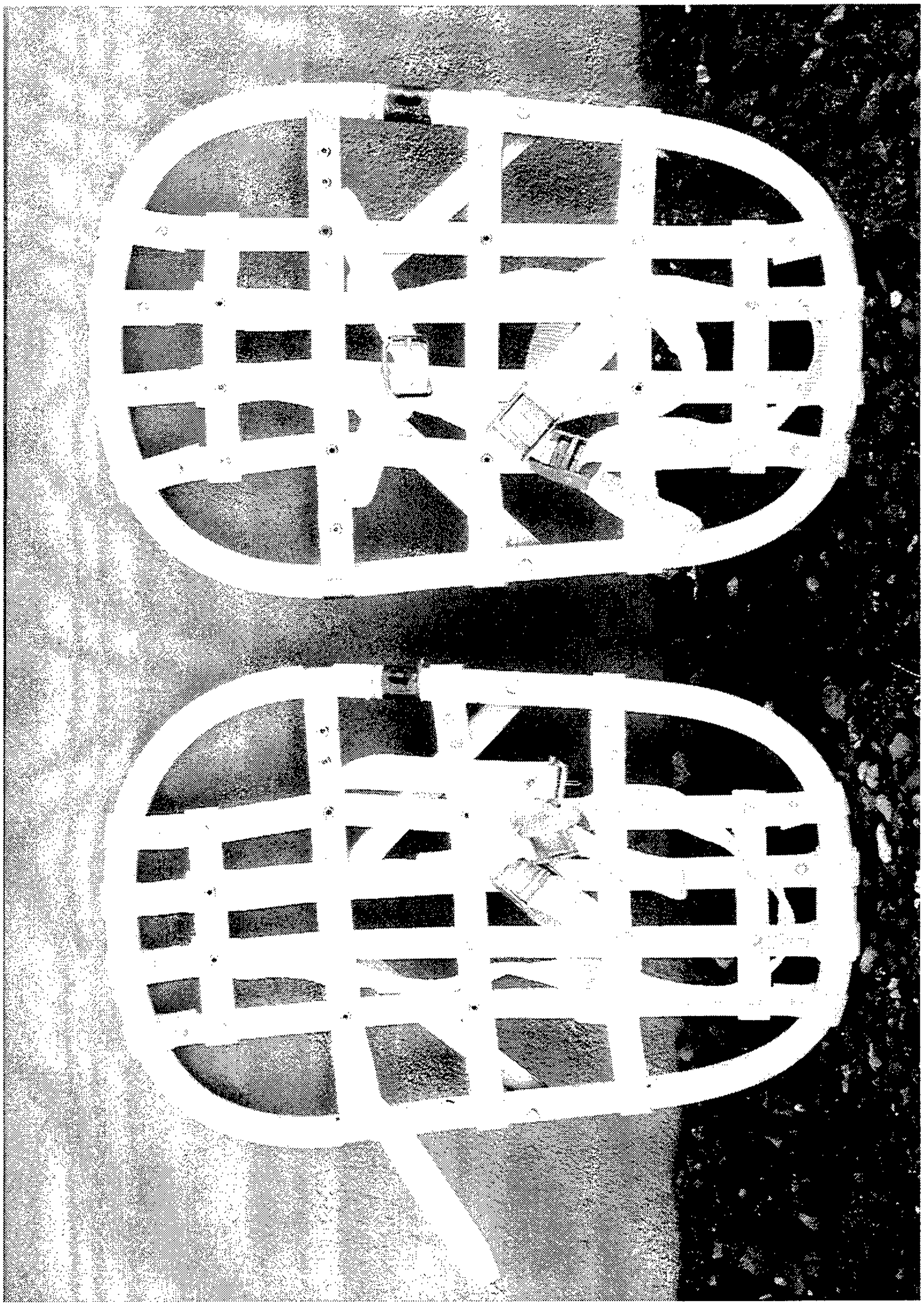

Figure 5. Top view of British assault snowshoe.

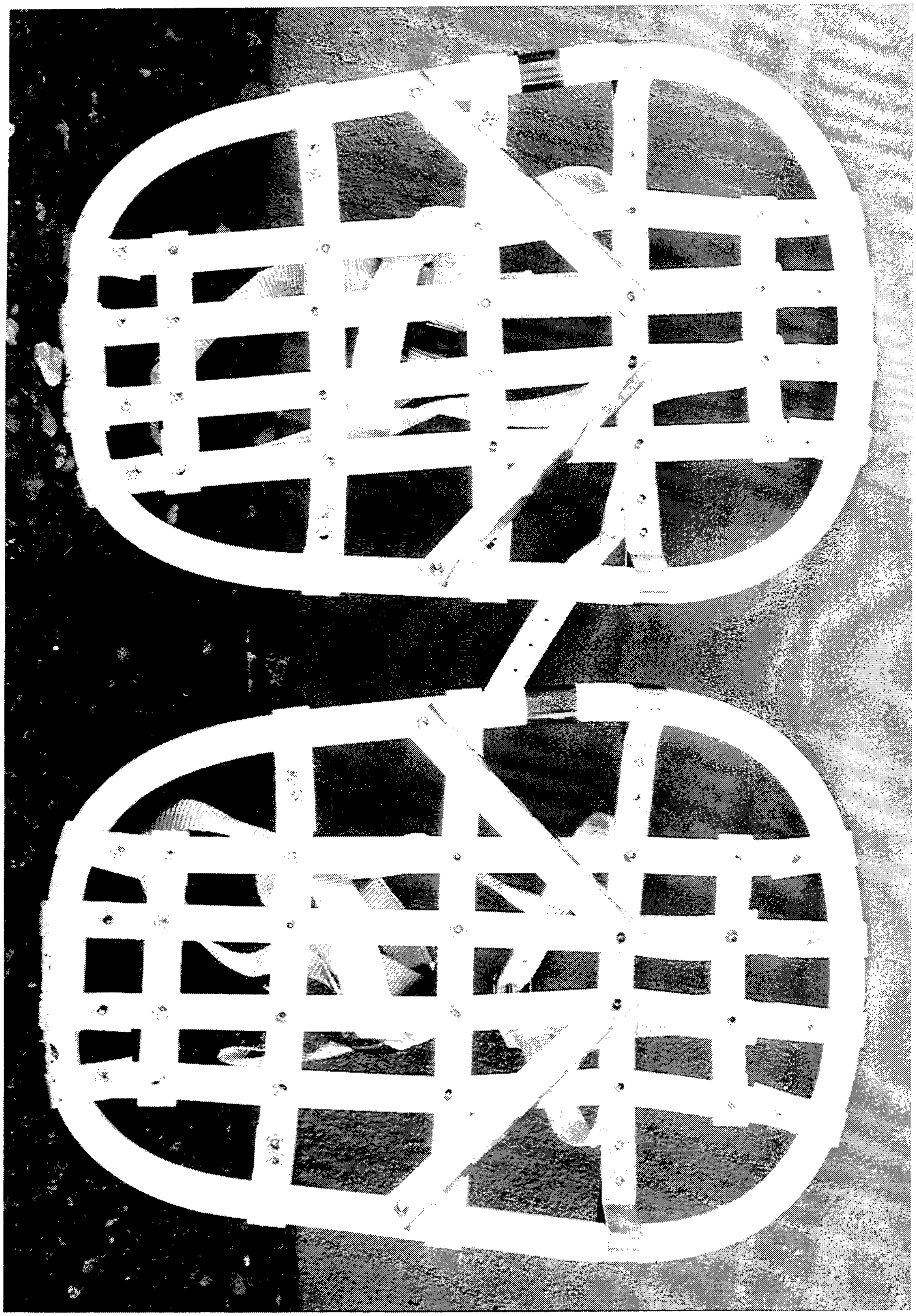

Figure 6. Bottom view of British assault snowshoe.

Figure 7. Top view of U.S. Army standard snowshoe.

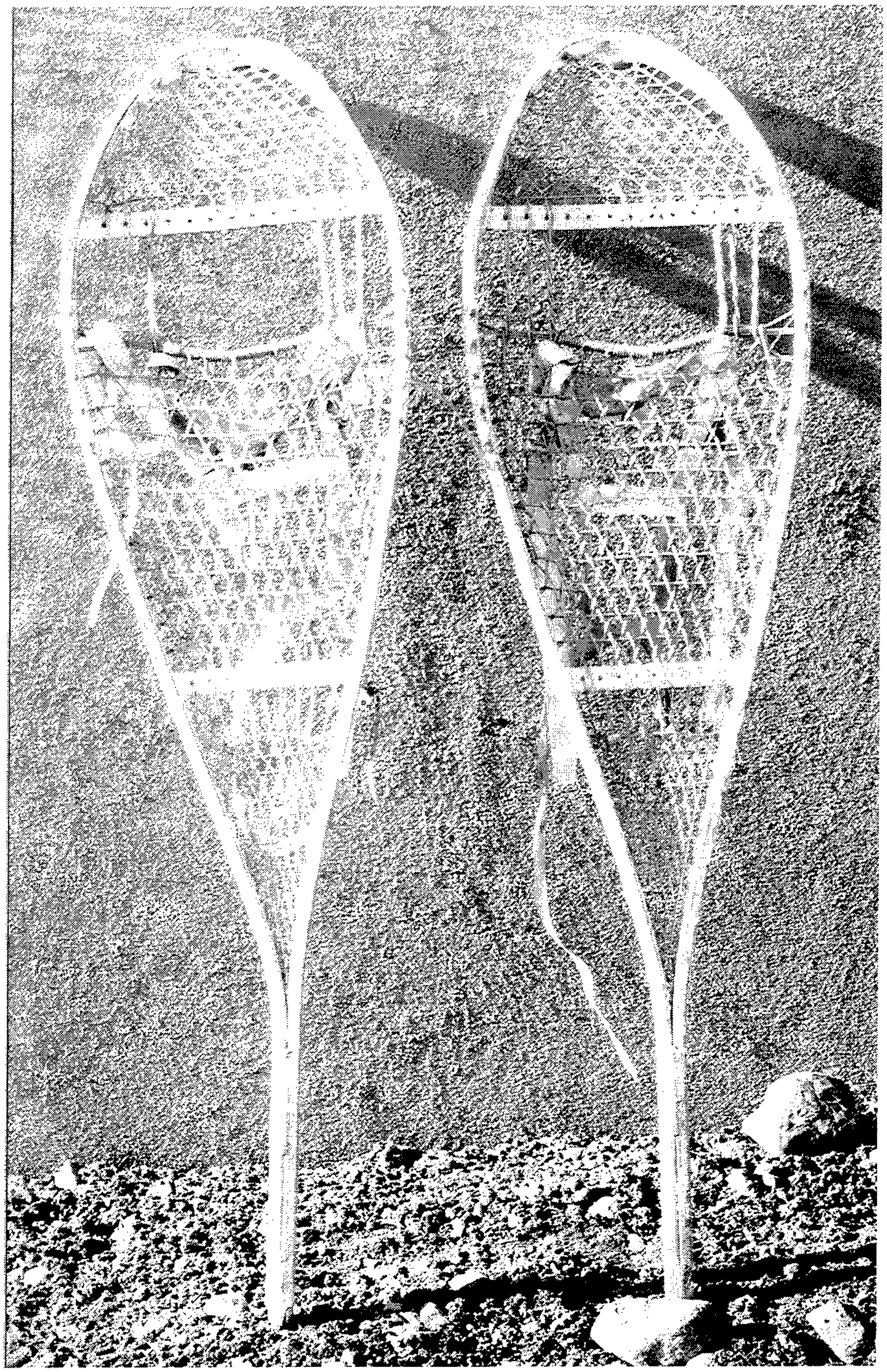

Figure 8. Bottom view of U.S. Army standard snowshoe.

To gauge flotation, the depth of depression was measured. Flotation is the inverse of depression, that is, the greater the depression, the less the flotation. Depression was measured with a ruler after Marines began walking in the snow. A straight edge was placed horizontally across the snowshoe print. A ruler was used to make four vertical measurements on the lateral, medial, and posterior portions of the snowshoe imprint. The deepest impression was also measured. To obtain a measure of overall depression, the lateral, medial, and posterior values were summed and averaged. The deepest depression was not included in the measure of overall depression because the characteristics of some snowshoes would have an unduly large influence on this measure (i.e., the crampon on the Pride or the toe pivot on the Standard).

Heart Rate

Heart rate was determined using a Polar Vantage XL® heart rate watch (Polar USA, Stamford, Connecticut). The device consisted of a sensor strap and watch. The subject wore the sensor strap around his chest. The watch was placed on the Oxylog2® device to allow technicians to read it easily. The strap contained electrodes that detected electrical signals from the heart and transmitted them to the watch.

Oxylog2® Device

The Oxylog2® device (PK Morgan, Chatham, United Kingdom) was designed to measure oxygen consumption (VO_2) and ventilation (V_E) in ambulatory subjects. The subjects' expired air was passed to the central Oxylog2® unit which contained a FIGARO KE-25 oxygen fuel type cell. The PO_2 difference between the inspired and expired air was measured in the instrument, and the volume of oxygen extracted was calculated. A turbine flow meter attached to the air intake side calculated the volume of the subjects' inspired air. A display on the device provided the VO_2 and V_E, which were averaged as minute values.

Marines wore a large pediatric mouth breathing face mask (Hans Rudolph Inc., Kansas City, Missouri, Series 7970) connected to the central Oxylog2® unit with Warren Collins (Braintree, Massachusetts) plastic spiral tubing. The Oxylog2® turbine flow meter was connected to the inlet valve of the face mask with Warren Collins molded couplers. The entire device weighed 2.3 kg.

Procedures

The snowshoe course was situated on a meadow in the Sierra Mountains of California

near the Marine Corps Mountain Warfare Training Center, Bridgeport, California (Sonora Pass Area). A 336-meter course was delineated on a helicopter landing zone. The course was not flat. An estimate of the slope obtained using survey techniques found the grade to be 2.4%.

All measurements were made on a single day and it had snowed the night before. Conditions were about 8 cm of powder snow on a base of about 60 cm of crust. In the days before the snowfall, temperatures had routinely achieved 10° C during the day, dropping below 0° C at night. Thus, the base snow had repeatedly frozen and thawed. Temperatures during the energy cost testing ranged from -3° C to 2° C.

Procedures during the testing were as follow. The Marines' mass in BDUs was obtained from a digital scale. They then donned the Oxylog2® device and the mask was fitted. The central Oxylog2® unit was contained in an insulated carrying case that was suspended from the subject's hips. The case was stabilized with straps across the Marine's shoulders and waist. While the Marine was changing snowshoes, he removed the mask by pulling it down to his neck. Just before walking, he put the mask back on and waited 1 minute before beginning to walk.

One of the investigators walked with each Marine and provided pacing information. The Marine was told that the goal was to achieve a pace of 4 km/hr (1.12 m/sec, 2.5 mi/hr). Poles were placed in the snow along the course, alternating every 20 m and 10 m. Between the 20-m markers, the investigator obtained the time to cover the distance. During the 10-m distance, the investigator consulted a chart relating time to distance and the Marine was provided his current speed. Information given the Marine was in the form of the speed for the previous 20-m segment (e.g., "4.2, that is a little fast; slow it down just a bit"). This process was repeated every 30 m. Marines were easily able to adjust their pace within 1 to 2 minutes of walking. Time to complete the entire 336-m distance was recorded at the end of the walk and converted to average speed for the distance.

Marines completed two walks with each of the four snowshoe models. Marines walked for about 5 minutes on the downhill leg of the course, then reversed direction and walked for about 5 minutes on the uphill leg. They then changed snowshoes and repeated the process. The order of presentation of the snowshoes is shown in Table 1. Marines always walked on fresh snow by progressively moving to the eastern side of their previous tracks. Measurements were obtained from the digital displays on the Oxylog2® and heart rate monitors at 3.5 minutes and at 5 minutes of the walk. Ventilation (l/min), oxygen uptake (l/min), and heart rate (beats/min) were recorded on paper.

Table 1

Order of Snowshoe Presentation

Marine identification number	Presentation order 1	2	3	4
1	Pride	Montana	British	Standard
2	Montana	Standard	Pride	British
3	British	Pride	Standard	Montana
4	Standard	British	Montana	Pride

Data Analysis

Data were analyzed using a one-way repeated measures analysis of variance (ANOVA), testing the hypothesis of no difference among snowshoes. When significant differences were found, differences between snowshoes were determined with the Tukey Honestly Significant Difference (HSD) Test. Pearson product moment correlations were used to examine the relationship between oxygen consumption and flotation measures. In order to examine the relationship between snowshoe characteristics and oxygen consumption, Pearson product moment correlations were performed between the average oxygen consumption for each snowshoe (uphill and downhill legs separately) and the snowshoe characteristics.

RESULTS

The physical characteristics of the four Marines are shown in Table 2.

The physical characteristics of the snowshoes are presented in Table 3. The two surface area measurements did not differ by more than 0.6%, so the values were averaged. The correlation between snowshoe mass and surface area was 0.67 (p=0.33).

Table 2

Body Composition and Anthropometric Characteristics of the Marines

	Stature (cm)	Body mass (kg)	Body fat (percent)	Fat mass (kg)	Fat-free mass (kg)
Mean	174.2	73.2	16.5	12.5	60.7
SD	4.9	4.5	8.2	7.8	4.1

	Neck circumference (cm)	Abdominal circumference (cm)	Trochanterion height (cm)	Thigh length (cm)	Calf length (cm)	Body mass with uniform (kg)
Mean	36.7	83.4	91.6	39.5	37.2	77.6
SD	1.8	9.4	5.5	3.2	2.7	9.6

Table 3

Physical Characteristics of the Four Snowshoes

Manufacturer	Model	Size (cm) length	Size (cm) width	Mass (kg)	Surface area (cm^2) entire shoe	Surface area (cm^2) curve	Mass to surface area ratio (gm/cm^2)
Pride	Assault	74	22	2.4	1393	230	1.72
Montana	RWT	52	34	3.0	1649		1.82
British	Assault	46	30	2.0	1302		1.54
Standard	Trial magnesium	120	28	2.6	1892	335	1.37

Table 4 shows the measurements made on stride length and depression depth for each of the four snowshoes. A lower number for depression would indicate better flotation (less depression into the snow). There were no significant differences among the snowshoes on any measure.

Table 4

Stride Length and Flotation Measures

	Stride length (cm)	Flotation measures: Medial depression (cm)	Lateral depression (cm)	Rear depression (cm)	Deepest depression (cm)	Overall depression (cm)
Pride	73.5±2.3	5.4±0.7	5.0±0.8	5.5±0.5	6.9±0.5	5.3±0.9
Montana	74.4±3.1	5.3±0.2	5.5±0.3	6.0±0.9	6.0±0.4	5.6±0.7
British	73.2±1.7	4.9±0.8	5.3±0.7	5.7±0.7	5.7±0.5	5.3±1.3
Standard	70.7±3.1	5.5±0.3	4.3±0.5	5.0±0.5	5.8±0.3	4.9±0.8
F-value	0.38	0.18	0.70	0.65	2.13	0.38
p-value	0.77	0.91	0.57	0.60	0.17	0.77

Table 5 shows the speed at which Marines completed the 5-minute walks on both the uphill and downhill legs of the course. There were no significant differences among the snowshoes.

Table 5

Actual Speed of Walking During Snowshoe Testing

	Speed on uphill (km/hr)	Speed on downhill (km/hr)
Pride	4.1±0.0	4.1±0.1
Montana	4.1±0.1	3.9±0.2
British	4.1±0.1	4.2±0.4
Standard	4.0±0.2	4.0±0.1
F-value	1.88	1.19
p-value	0.20	0.37

Table 6 shows the cardiorespiratory values for the four models of snowshoes when Marines were on the downhill leg of the course. These are the average of the values taken at 3.5 minutes and 5 minutes since a paired t-test showed no difference between the two periods for any measure. The Tukey test on the VO_2 values revealed that the Pride and the Standard snowshoes had a significantly lower energy cost than the Montana ($p<0.05$) but the British did not differ from any other snowshoe (critical difference = 0.17 for absolute VO_2 (l/min) and 2.36 for relative VO_2 (ml/kg*min). For V_E, the Tukey test indicated that the Montana produced significantly higher values than any of the other three snowshoes but there were no significant differences among the Pride, British, or Standard shoes (critical difference = 5.4).

Table 6

Cardiorespiratory Values for the Four Snowshoe Models on the Downhill Portion of the Course

	Heart rate (beats/min)	VO_2 (l/min)	VO_2 (ml/kg*min)	V_E (l/min)
Pride	122.9±14.2	1.25±0.13	17.4±3.2	24.5±6.1
Montana	136.0±11.1	1.46±0.11	20.2±2.7	30.0±6.2
British	130.4±14.4	1.31±0.13	18.2±3.7	24.4±4.3
Standard	123.3±7.3	1.22±0.20	16.8±2.3	20.6±2.6
F-value	2.09	7.79	7.36	8.69
p-value	0.17	0.01	0.01	0.01

Table 7 shows the cardiorespiratory values for the four snowshoes when Marines were on the uphill portion of the course. The rank of snowshoes with regard to energy cost and heart rate was similar to the downhill portion (see Table 6).

Table 8 shows the Pearson product moment correlation coefficients between the flotation measures and oxygen uptake for each snowshoe. The pattern of correlations suggests that lower energy cost is associated with less depression for the Pride and Montana, but this pattern is not seen with the British or Standard snowshoes.

Table 7

Cardiorespiratory Values for the Four Snowshoes on the Uphill Portion of the Course

	Heart rate (beats/min)	VO_2 (l/min)	VO_2 (ml/kg*min)	V_E (l/min)
Pride	143.4±14.6	1.58±0.12	22.0±4.0	32.6±9.7
Montana	154.6±7.3	1.78±0.14	24.5±2.8	36.7±10.8
British	151.4±11.1	1.62±0.21	22.6±4.9	32.2±9.0
Standard	143.6±8.4	1.51±0.06	21.0±3.3	30.1±5.1
F-value	3.35	3.69	3.47	1.96
p-value	0.07	0.06	0.06	0.19

Table 8

Correlation Coefficients Between Measures of Snowshoe Depression and Oxygen Consumption

		Deepest depression	Overall depression
VO_2 (l/min)	Pride (downhill)	0.96	0.65
	Pride (uphill)	0.51	0.31
	Montana (downhill)	0.69	0.24
	Montana (uphill)	0.48	0.89
	British (downhill)	-0.66	-0.20
	British (uphill)	0.06	0.56
	Standard (downhill)	0.11	-0.26
	Standard (uphill)	0.16	-0.17
VO_2 (ml/kg*min)	Pride (downhill)	0.81	0.71
	Pride (uphill)	0.50	0.50
	Montana (downhill)	0.83	0.26
	Montana (uphill)	0.82	0.72
	British (downhill)	-0.53	-0.09
	British (uphill)	-0.15	0.36
	Standard (downhill)	0.01	-0.33
	Standard (uphill)	0.04	-0.29

Table 9 displays correlations between various snowshoe characteristics and average oxygen uptake. The mass-to-surface-area ratio demonstrated the highest relationships and Figure 9 displays this. Examination of Figure 9 suggests that the Montana, British, and Standard snowshoes demonstrate proportional increases in oxygen consumption with increasing mass-surface area. The Pride, however, departs from this trend showing less of an increase for its surface area.

Table 9

Correlations Between Snowshoe Characteristics and
Average Oxygen Consumption

Snowshoe characteristic	Oxygen comsumption downhill	Oxygen comsumption uphill
Mass	0.51	0.54
Surface area	-0.17	-0.08
Mass-surface area	0.81	0.72

DISCUSSION

Comparisons Among Snowshoes

The small number of Marines makes any conclusions drawn from this study tentative. However, even with the small sample size, we found differences between the snowshoe models. The Montana had a significantly higher energy cost than the Pride or Standard snowshoes on the downhill portion of the course and this same trend was duplicated on the uphill portion of the course. The British snowshoe tended to have a higher energy cost than the Prides or Standards, but this was not statistically significant.

Because of the small number of subjects, we performed a statistical power analysis to further examine differences between the British snowshoe verses the Pride and Standard. The techniques of Cohen (1977) were used. An α of 0.05 and power of 0.80 were assumed and effect sizes were calculated as $Mean_1$-$Mean_2/\sigma$ (in which σ is the average of the standard deviations of the two means). Results are shown in Table 10. These results suggest that with larger sample sizes the Pride and Standard snowshoes could demonstrate lower energy cost than the British snowshoe.

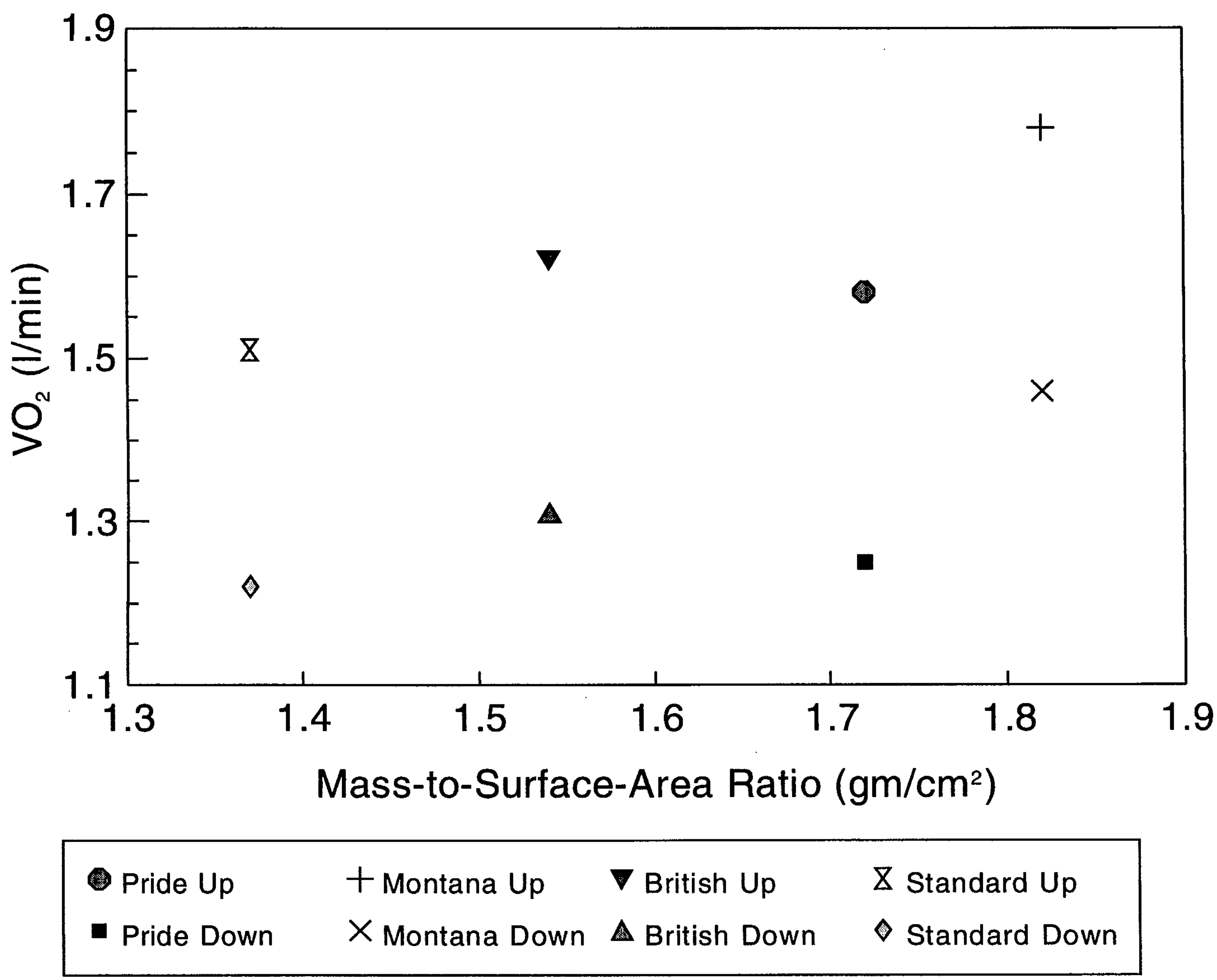

Figure 9. The relationship of oxygen uptake and snowshoe mass-to-surface-area ratio.

Table 10

Statistical Power Analysis of Snowshoe Types Based on Data from This Study (assumes α=0.05 and power=0.80)

Course	Comparison	Effect size	Approximate sample size needed
Downhill	Standard versus British	0.53	50
	Pride versus British	0.46	50
Uphill	Standard versus British	0.85	20
	Pride versus British	0.24	138

The Montana snowshoe made walking most difficult for the Marines. This model tended to be very flexible since it was composed of automotive tire rubber. It could deform easily and tended to fold under often, causing the Marines to change their gait and stumble forward at times (although no one actually fell). Also, the Montana was wider than the other snowshoes, causing somewhat more abduction of the legs at the hips and more of a waddling gait than the other snowshoes. Gait adjustments and stumbling could have been significant factors in the higher energy cost. The Montana was also the heaviest of all the snowshoes and it has been shown that greater mass on the foot has a large effect on energy cost (Jones, Knapik, Daniels, & Toner, 1986; Jones et al., 1984).

The energy cost of the Pride and Standard snowshoes was lower than that of the Montana. The Pride and Standard shoes share two common characteristics. First, they have a hinge and binding system that allows the snowshoe to be dragged in the snow. With more of the snowshoe mass supported on the snow, less total mass (leg plus snowshoe) may have been lifted, thus reducing energy cost. The British and Montana had to be raised almost vertically out of the snow to avoid tripping. This additional vertical distance (relative to the Pride and Standard) may have contributed to the higher energy cost. The second common characteristic shared by the Pride and Standard shoes is an upturned front (the curved portion). This allows the snow to be pushed to the front and side, permitting the shoe to be elevated out of the depression in a more horizontal direction. This may also assist in reducing the vertical component of the leg-plus-snowshoe lift.

The correlational analysis suggested that a low mass-to-surface-area ratio is associated with a lower energy cost. Such a ratio would be achieved with a light snowshoe covering a large area of snow. Thus, reducing mass with lightweight materials while increasing surface area may be desirable in snowshoe design.

These data suggest that favorable characteristics of snowshoes from an energy cost perspective may be 1) a hinge and binding system that allows the snowshoe to be dragged across the snow, 2) an upturned front that pushes snow and allows a more horizontal displacement of the snowshoe, and 3) lightweight snowshoe materials combined with greater surface area. Further research will be necessary to determine the relative importance of these design characteristics, given the small number of Marines in this study.

Comparisons Among Studies

Table 11 shows a comparison of the results of the present study with others that have examined the energy cost of snowshoeing. The difficulty of making direct comparisons is immediately apparent. There are differences in walking speed, and most studies do not report grade, depth of depression, or mass carried, despite the importance of these variables to energy cost (Goldman & Iampietro, 1962; Heinonen et al., 1959; Pandolf et al., 1976; Ramaswamy et al., 1966). Further, Rodgers et al. (1965) noted that energy cost will vary with the skill of the user; they reported that one of their subjects actually used more energy with snowshoes than without. Our Marines trained a full day with each snowshoe and were very familiar with them by the time the energy cost studies were conducted. In addition to these considerations, the findings here suggest that certain characteristics of the snowshoe can influence energy cost and none of the studies report these characteristics.

We used the Pandolf equation (Pandolf et al., 1977) to estimate the energy cost of walking in the snow, assuming the conditions of our study. This could only be done for the uphill portion of the course since the equation does not accurately estimate the metabolic rate for downhill walking (Knapik, Harman, & Reynolds, 1996). For the uphill calculation, we used a grade of 2.4% and a walking speed of 1.12 m/sec. The subject's load mass was the weight of the uniform plus the weight of the Oxylog2®. Terrain factors were calculated from the overall depression for each snowshoe (Pandolf et al., 1976). Metabolic rates were converted to kilocalories (kcals), assuming that 1 watt = 0.01433 kcals. Kilocalories were converted to oxygen uptake values, assuming that 1 liter of oxygen is the metabolic equivalent of 5 kcals (on the Oxylog2®). It was assumed that energy cost would increase 10% for each kg of snowshoe

weight (Jones et al., 1986; Jones et al., 1984). Values based on these assumptions are given in Table 12 and compared to actual energy cost values. The Pandolf equation underestimated the oxygen consumption rate by 7%, 16%, 11%, and 3% for the Pride, Montana, British, and Standard snowshoes, respectively. Note that the Pandolf equation was developed for walking in boots and has not been validated for snowshoes.

Table 11

The Energy Cost of Walking in Snowshoes in Various Studies
(NR=not reported; CBC=cannot be calculated)

Study	Depression (cm)	Subject body (kg)	Grade (percent)	Speed (km/hr)	VO2 (l/min)	VO2 (ml/kg*min)
Buskirk et al. (1956)	NR	75	NR	3.7	1.28	17.5
Rodgers et al. (1965)	9	70	Near zero (on frozen river)	3.7	2.45	35.0
Allen & O'Hara (1973)	NR	NR	NR	2.0-3.6	0.97	CBC
Worsley et al. (1974)[a]	<5	67	NR	3.6 4.8	~1.3 ~1.7	~19 ~25
Present study (downhill)	5	73	-.24	4.0	1.22-1.46	16.8-20.2
Present study (uphill)	5	73	+2.4	4.0	1.51-1.78	21.0-24.5

[a]Authors noted that subjects had a pack but provided no pack mass; energy cost values estimate from equation (VO_2(ml/kg*min)=-1.3+0.33*speed(m/min) and Figure V.2 in Worsley et al. (1974)

Snow Conditions

Snow conditions were such that walking was not difficult for Marines in this study. The 8 cm of new snow was very soft and powdery. The 5 cm of average depression indicated that the snowshoes elevated Marines about 3 cm above the snow base. It will be critical in future studies to provide better descriptions and quantification of snow conditions, as these may alter energy cost measures.

Table 12

Estimates of Metabolic Rates, Energy Expenditure Rates, and VO_2 (from Pandolf Equation) Compared to Actual VO_2 During Uphill Walking at 2.4% Grade

	Estimates based on Pandolf equation			
Snowshoe	Metabolic rate (watts)	Energy expenditure rate (kcal/min)	VO_2 (l/min)	Actual VO_2 (l/min)
Pride	504	7.22	1.47	1.58
Montana	508	7.28	1.50	1.78
British	504	7.22	1.47	1.62
Standard	495	7.09	1.46	1.51

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13. ABSTRACT *(Maximum 200 words)*

Energy cost was examined while four Marines walked at 4 km/hr on an open field with each of four snowshoes. Snowshoes were the Pride Assault, Montana, British Assault, and the U.S. Army Standard. The grade of the field was about 2.4% and the Marine walked once downhill and once uphill with each snowshoe. Expired respiratory gases were collected continuously during each walk. On the downhill portion of the course, average $\pm$ standard deviation (SD) VO_2 values were 1.25 ± 0.13, 1.46 ± 0.11, 1.31 ± 0.13, and 1.22 ± 0.20 l/min for the Pride, Montana, British, and Standard snowshoes, respectively (p=0.01); the Pride and Standard snowshoes had significantly lower energy cost than the Montana (p=0.05). On the uphill portion of the course, average $\pm$ SD VO_2 values were 1.58 ± 0.12, 1.7 ± 80.14, 1.62 ± 0.21, and 1.5 ± 10.06 l/min for Pride, Montana, British, and Standard snowshoes, respectively (p=0.06). Data suggested that several characteristics may be favorable from an energy cost perspective: 1) a foot hinge and binding system that allows the snowshoe to be dragged across the snow, 2) an upturned front that pushes snow away and allows a more horizontal displacement of the snowshoe during locomotion, and 3) a lower mass-to-surface-area ratio. Further research will be necessary to determine the relative importance of these design characteristics, given the small number of subjects.

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